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DEPARTMENT OF COMMERCE * UNITED STATES OF AMERICA *

AUTOMATIC EVAPORATION MEASUREMENT SYSTEM (AUTOVAP) DEVELOPMENT REPORT

Silver Spring, Md.
June 1978

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NWS EDL 16 No-Moving Parts Anemometer Design Analysis Program. Anthony W. Cheek and Charles F. Lambert, October 1977. (PB-277-524)

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AUTOMATIC EVAPORATION MEASUREMENT SYSTEM (AUTOVAP) DEVELOPMENT REPORT

Anthony W. Cheek and Charles F. Lambert

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**UNITED STATES
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AUTOMATIC EVAPORATION MEASUREMENT SYSTEM (AUTOVAP) DEVELOPMENT PROGRAM

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ABSTRACT. This report describes a system for automatically measuring, storing and displaying the amount of evaporation from an insulated evaporation pan. Also, the system is capable of:

- maintaining a constant water level in the evaporation pan
- removing water from the pan when precipitation occurs
- storing the water in a reservoir
- replenishing water in the pan when evaporation occurs

The automatic evaporation measurement system, AUTOVAP, was originally designed for a 2 week unattended battery operation. However, with the addition of a battery charger the system can be used on a continuous basis. Other optional design features are available including power supply operation and DARDC compatibility.

1. INTRODUCTION

Over weekends and vacation periods when observers are away, there are occasions when data is not recorded. The primary object in developing the system was to automate the evaporation observation, AUTOVAP.

There are three optional AUTOVAP systems available for procurement. The first option designed by the Equipment Development Laboratory operated on a battery and trickle charger and had a liquid crystal display (LCD). The LCD displayed both "Water added" and "Water removed" from the evaporation pan in tenths of a millimeter and the data was manually recorded. There are two other options available depending on the location where the AUTOVAP system will be installed. One contains a battery and trickle charger without the LCD but, is capable of interfacing with the Device for Automatic Remote Data Collection (DARDC). The third option consists of a 12 volt power supply without the LCD but with DARDC capability. Therefore, data can be collected with these three options either locally or remotely.

2. REQUIREMENTS

The requirements as supplied by the Office of Hydrology are listed below. The system should automatically:

1. Obtain evaporation measurement in 0.2-mm increments.

2. Maintain a constant water level in the evaporation pan.

3. Remove water from evaporation pan.

4. Handle rainfall at the rate of 150 mm per hour.

5. Operate unattended for approximately two weeks.

6. Operate on batteries.

7. Operate on a power supply.

8. Record both water added and water removed from the evaporation pan.

3. SYSTEM DESCRIPTION

The AUTOVAP system (fig. 1) is designed to automatically measure, in engineering units, the evaporation and precipitation occurring in an evaporation pan. The system consists of three main assemblies: the insulated evaporation pan, the control box, and the reservoir. The evaporation pan is where a constant water level must be maintained and the water level is sensed. The control box maintains a constant water level by pumping water in or out of the evaporation pan. The reservoir supplies the water during evaporation and holds the excess water during precipitation.

3.1 Insulated evaporation pan

The insulated evaporation pan is a circular, insulated pan with approximately 615-mm inside diameter, 610-mm depth, and an 83-mm wall thickness. A stilling well, located in the wall of the pan adjacent to the main body of water, is where the water level is sensed. The inner and outer shells of the pan are 3.2 mm Fiberglas with a freon blown polyurethane foam insulation between them.

3.2 Liquid level sensing device

The liquid level sensing device consists of a probe assembly (fig. 2) mounted in the stilling well of the evaporation pan. It has three pointed stainless steel probes which indicate three different water levels, and one longer stainless steel rod that keeps the water grounded with respect to the control circuitry. As the water level changes each probe sends a signal to the control circuitry when its level is reached. When the water level is below the lowest pointed probe, the evaporation probe signals the control circuitry that evaporation has occurred and water must be added until an acceptable water level is reached (between the lowest probe and the next higher probe). When the water level rises to the next probe, the precipitation probe, precipitation is indicated and water is removed until an acceptable water level is reached. The acceptable water level (neutral region) lies between these two probes, a 0.4 mm separation, where no pumping of water takes place. When the water level reaches the third probe, heavy precipitation probe, 6.35 mm above the evaporation probe, heavy precipitation

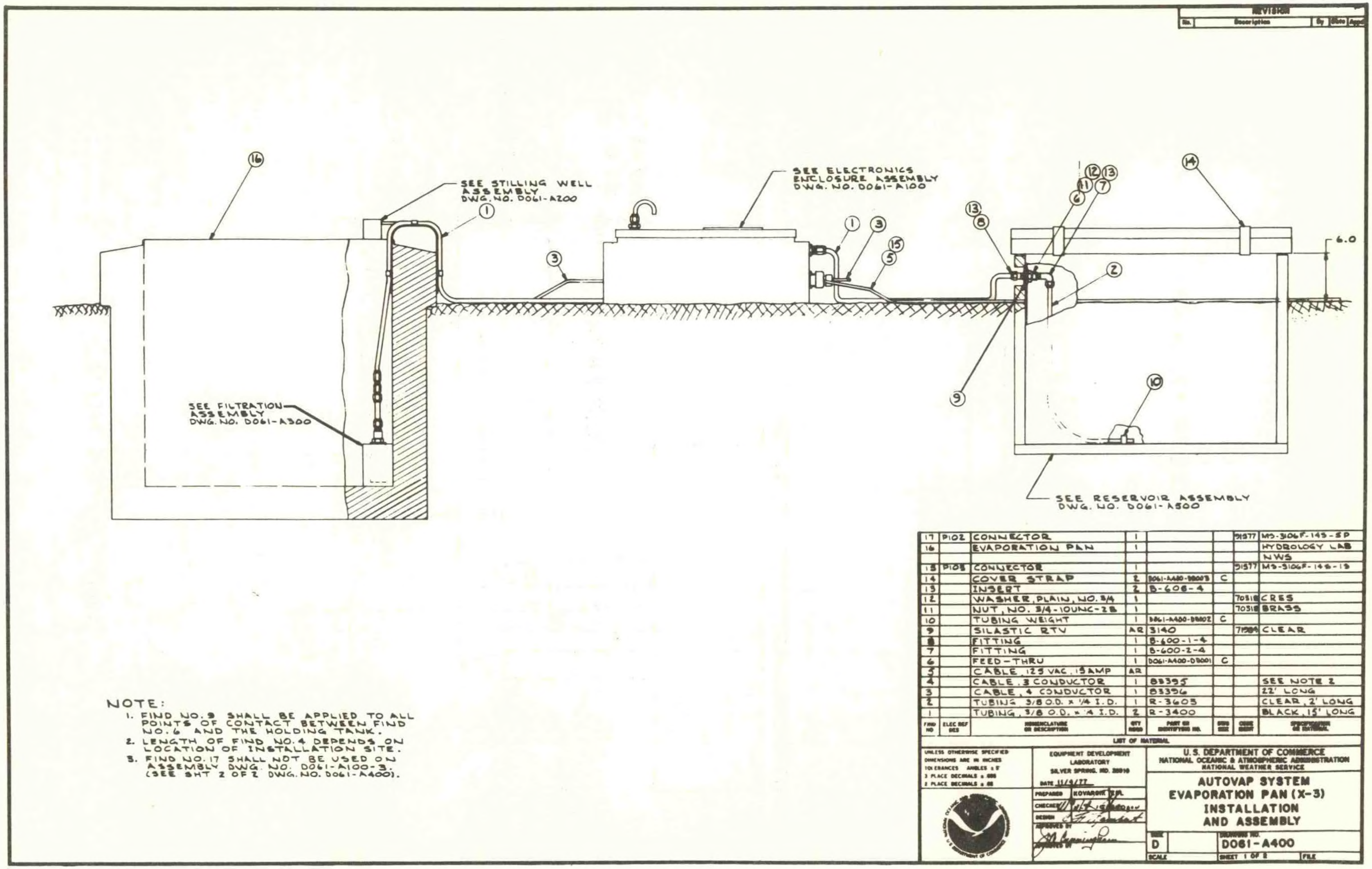

Figure 1.--AUTOVAP system

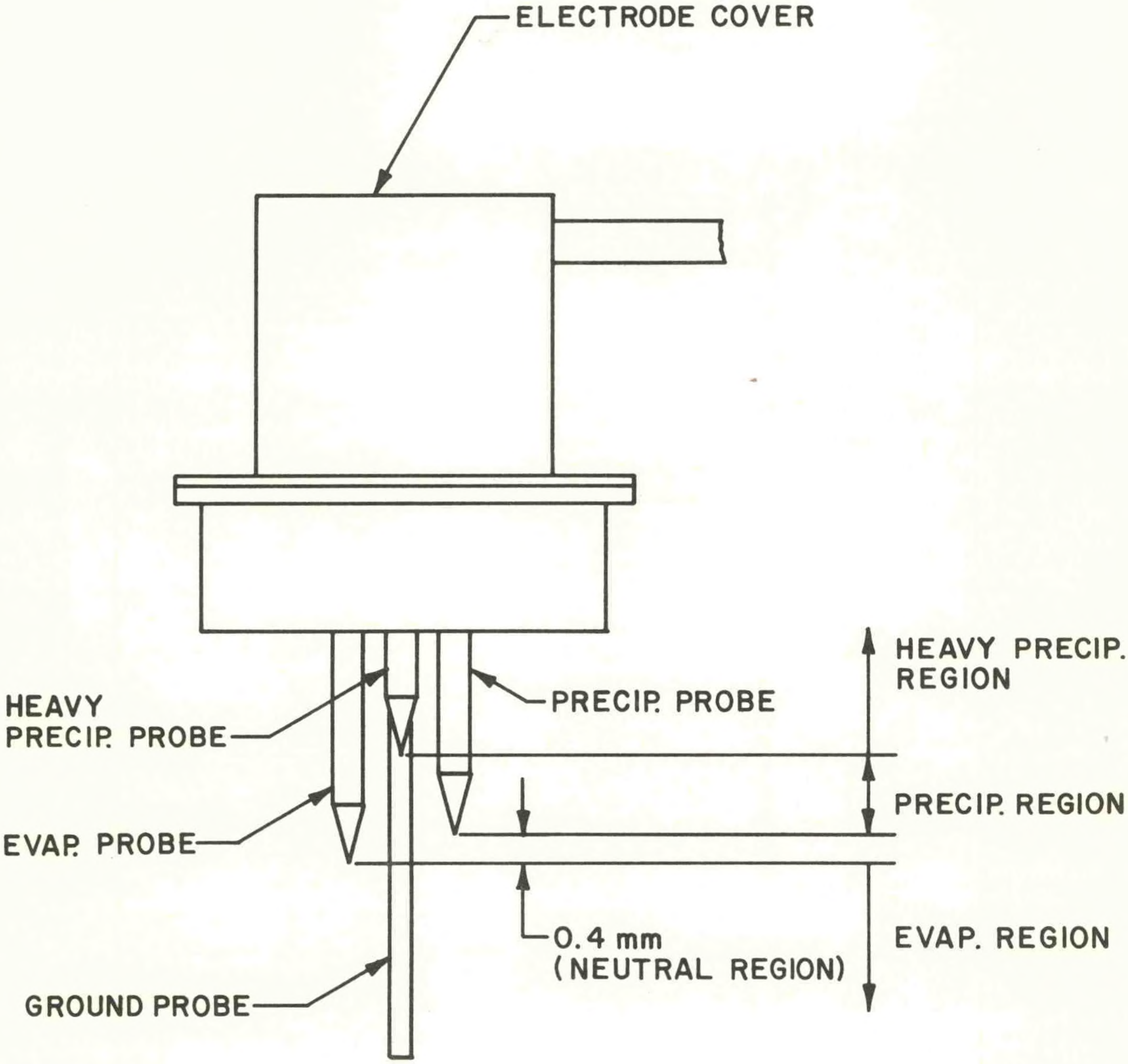

Figure 2.--Probe assembly

is indicated, causing the control circuitry to remove water at a faster rate until the water level drops below this third probe. Below the third probe, water is removed at a normal rate until the water level reaches the acceptable water level region where pumping is discontinued. The main purpose of the probes is to inform the control circuitry of changes in water level.

3.3 Filtration system

Water is pumped into and out of the evaporation pan through a triple filtered plastic tube that connects to the control box. Two filters are located at the bottom of the pan, both a large mesh filter for objects, such as leaves, and a smaller mesh filter to prevent particles larger than 1.5 mm from entering the plastic tubing. A 250-micron in-line filter is located inside the plastic tubing that leads to the pump. Periodic cleaning of the filters is dependent on the amount of debris collected in the water at the various installations.

3.4 Control box

The control box along with the probe assembly maintains a constant water level in the evaporation pan with the use of a reversible pump motor, solenoid valve, 12-volt rechargeable battery, (or 12-volt power supply) battery charger, and a printed circuit (P.C.) control module. The control module manipulates the pump motor and solenoid valve to deliver equal discrete quantities of water in either direction of flow. The solenoid valve prevents any siphoning between the evaporation pan and the reservoir. The 12-volt rechargeable battery is the power supply for the entire system and is trickle charged by the battery charger. A light emitting diode (LED) on the control module indicates when the battery is low. For calibration purposes, a toggle switch is mounted on the control module that enables the operator to go to a faster pumping rate.

The control module consists of three timing circuits used to maintain a slow or fast rate of flow of equal discrete quantities of water to keep an acceptable water level at approximately 50 mm below the top of the evaporation pan. One timing circuit controls how much water each pump cycle shall deliver. This time interval is approximately 2 to 3 seconds and is adjusted to pump 59.3 ml of water, equivalent to a change in water level in the pan of about 0.2 mm. Another timing circuit specifies the time in which the water must continuously touch the evaporation and/or the precipitation probes before a valid evaporation or precipitation state is determined. This time interval is approximately 3 minutes (due to wind effects) and is adjustable to up to 8 minutes. The other timing circuit controls how much of a delay will occur between consecutive pumps at the faster pumping rate when the water level reaches the heavy precipitation probe. This time interval is approximately one second and is not adjustable.

Other adjustments on the control module include a pump voltage regulator adjustment that is set at 8.5 VDC and a low battery voltage indicator adjustment that is set to trigger an LED when the battery voltage drops below 10.5 VDC.

Within the control box is a switching panel that allows automatic operation of draining or filling of the evaporation pan. Automatic operation is the maintenance of a desired water level, and a record of "WATER ADDED" and "WATER REMOVED" is maintained. In the draining or filling mode the pump is powered directly from the 12-volt battery and runs continuously, but there is no record of the amount of water pumped.

Also available in the control box is a liquid crystal display (LCD) P.C. module which counts the number of tenths of a millimeter of water added or removed (evaporation or precipitation) from the pan. A push button reset switch is mounted on this module that resets both counts. This module is not essential to the system's operation and is one of the procurement options.

The system can also be connected to a DARDC unit as well as the LCD card through a weatherproof connector on the control box. Both devices report information in tenths of a millimeter and either one or both devices can be used at any time.

3.5 Reservoir

The reservoir is a covered polyethylene plastic tank that is initially filled and stored with excess rain water. It supplies the evaporation pan with water whenever evaporation has occurred. A small overflow hole in the side of the reservoir near the top of the tank will allow water to escape in the event an excess quantity of water is pumped into the reservoir. Flexible, black vinyl plastic tubing connects the reservoir tank to the control box and the control box to the pan.

4. DEVELOPMENT

The development of the AUTOVAP system was based on the measurement process carried out by the observer. A constant water level is maintained in the evaporation pan by adding or removing a measured quantity of water in the event of evaporation or precipitation. A record of the water added, implying evaporation has occurred, and water removed, implying precipitation has occurred, is tallied yielding both evaporation and precipitation data.

To perform the above measurement process a water level sensing device to maintain a constant water level was created using stainless steel probes and low power consuming digital logic. To transport water in and out of the evaporation pan, a small reversible voltage-controlled pump motor was selected (from 18 candidate pumps) that delivers a constant flow in both directions. In order to keep a record of the amount of water added and removed from the pan, a discrete burst method of pumping was adopted with each burst equaling 59.3 ml of water. This was accomplished with the control module pulsing the reversible pump motor and the solenoid valve appropriately, creating equal discrete quantities of water that could be counted. To supply and store water in order to maintain a constant water level, a heavy duty covered plastic tank was selected as a reservoir. A solenoid valve was incorporated into the system to prevent siphoning between the evaporation pan and reservoir. A battery operated control module was designed to connect and control these various components.

Two pointed stainless steel probes, with a 0.4 mm difference in height, are used to maintain the acceptable water level, (neutral region) (fig. 2). The evaporation probe signals an evaporation state when the water level is below it, and the precipitation probe signals a precipitation state when the water level is above it. Between the evaporation and precipitation probes is a neutral zone where no pumping takes place.

The difference in height of 0.4 mm between the evaporation and precipitation probes was determined through trial and error. Initially, a 0.2 mm separation was planned for since each pump delivers or removes 0.2 mm of water. Unfortunately, surface tension caused oscillation between the evaporation and precipitation states. After increasing the separation to 0.4 mm, oscillations due to surface tension ceased. Periodic cleaning of the probes is required to prevent a build up of dirt and impurities that may reduce the separation of the probes causing oscillations and incorrect data. The frequency of cleaning depends on the amount of debris and impurities collected by the water and the geographic location of the installed systems. Since the evaporation pan is exposed to the environment, three filters were added to prevent damage to the system. One filter is a cage type to keep leaves and other large debris from clogging the flow. The second filter is a finer mesh type that prevents smaller particles from entering the plastic tubing. The third filter traps 250 micron and larger particles that may damage the pump motor. These filters will require periodic maintenance (approximately every 3 months) depending on the amount of debris collected by the water in the pan in various areas.

One problem encountered with the probes was an electrical short developing due to condensation building up around the probes, also causing oscillation. To solve this problem a non-corrosive silicone rubber coating was applied around the probes to isolate them from moisture build up on the underside of the plastic probe support. The silicone rubber was removed from the probe tips where the sensing occurs.

Another source of oscillation was the wind turbulence causing wave action which created an oscillation between the evaporation and precipitation states. Several solutions were evaluated; reducing the opening between the stilling well and the main body of water in the evaporation pan; adding fluidic delay line to the stilling well; and incorporating an electrical delay in the circuitry. The electrical delay was found to be most satisfactory. A 3-minute timing cycle was determined to be sufficiently long to defeat oscillation due to wave action in gusty winds up to 28 knots.

When an evaporation or precipitation state is signaled by the probes the 3-minute timing cycle begins which is reset to zero if the water level causes the probes to change states. Only after the 3-minute cycle is completed will pumping begin. A normal 3-minute cycle is not completed unless the probes signal one particular state for 3 minutes continuously.

Under heavy rainfall conditions (in excess of 4 mm/hr) the 3-minute cycle between each pump cycle was found to be too long a time delay for maintaining a proper water level in the pan. A heavy precipitation probe was added to detect a large rainfall accumulation and signal the control module to pump at a faster rate. This faster rate has a one second, rather than a 3-minute, delay between pumps (and is capable of handling rainfall rates up to 200 mm/hr) until the water level falls below the heavy precipitation probe. Water is then removed from the pan at the normal rate until the water level falls within the neutral zone where pumping will cease.

The pump is controlled by the control module through a set of two relays, a voltage regulator, and a timing circuit. One relay chooses the direction of water flow while the other is responsible for pulsing both the pump and solenoid valve. The voltage regulator along with a timing circuit insures an equal amount of water flow during each discrete pump. Although the pump motor is rated at 12 VDC, the voltage applied is limited to 8.5 VDC because of the drop in the voltage regulator used during automatic operation. Under the draining or filling mode no regulation is applied so the pump operates directly off the 12-volt battery.

The liquid crystal display (LCD) module is designed to count and display the number of pulses that are sent by the control module. Two pulses per pump are sent by the control module with each pulse indicating a change in water level of 0.1 mm. A LCD was chosen over a light emitting diode (LED) display because of its lower power consumption and increased visibility in direct sunlight. A transflexive type of LCD is used which has the capability of being seen in strong sunlight or almost no light with no necessity for backlighting. The power consumption of LCD is 100 to 1000 times less than that of a LED display. A clear lexan window installed in the door of the control box permits viewing of the LCD without opening the control box. Both the LCD module and window are optional.

On models that don't contain the LCD module, the control module sends two pulses per pump cycle to an external connector at a lower voltage that is adaptable to the DARDC system. Two DARDC counter cards are required to report both evaporation and precipitation. Both cards are identical and require only two jumper wire changes to an interrogation counter card presently in the DARDC system.

5. TESTING

Tests were conducted on two AUTOVAP systems; one at the Test and Evaluation Division (T&ED), Sterling, Virginia, and one at the Equipment Development Laboratory (EDL).

5.1 Equipment Development Laboratory testing

Tests conducted by EDL were initially limited to component evaluation of the pump, battery, probes, control module,LCD module, and solenoid valve to determine design adequacy. Subsequent testing at EDL was performed on the entire system. The AUTOVAP system was placed on the 15th floor roof of the Gramax Building where wind effects and sun exposure could be analyzed. For 5 months the AUTOVAP system was under test with readings taken every hour during duty hours and the calibration was checked every day. During this time the delay time of 3 minutes was determined to be sufficient to defeat oscillations due to wind turbulence. Changes in the probe assembly were also made during the developmental testing. Two like tests were run on the battery which revealed an average life of approximately 21 days of operation from a fully charged battery. This battery lifetime value is primarily dependent on the number of pump operations. Frequent heavy rains will cause a decrease in the life of the battery especially if heavy rainfall occurs soon after the battery has been installed. This information on the draining characteristics of the battery agrees with data acquired from other applications of this battery.

5.2 Test and Evaluation Division testing

Tests conducted at T&ED consisted of chamber tests, wind tunnel tests and field tests during FY-76 and FY-77. Test results indicate the AUTOVAP system recorded 3.6% more evaporation than the International Network Evaporation Pan (INEP) over a 70-day test period. This is reasonable based on previous tests, conducted by the Office of Hydrology, to determine how the evaporation measurement changed with different depths from the top of the pan. When the pan is maintained at a constant level as with the AUTOVAP the evaporation is greater than a pan where the water level varies. No final test report is available at this time, however, additional test results and observations are listed in T&ED's letter dated May 24, 1977.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of the field tests conducted by the Test and Evaluation Division were very encouraging. AUTOVAP evaporation errors compared to the INEP pan were within 3.6% and clearly indicated automatic evaporation measurements are feasible. Based on the test results, it was recommended by the Office of Hydrology that three additional systems be built and field tested during FY-78 in the Southern, Central, and Western Regions.

APPENDIX A - INSTALLATION INSTRUCTIONS

Installation of the AUTOVAP system assumes that an insulated evaporation pan has already been installed (fig. 1). Instructions concerning the installation of the insulated pan are not included in these instructions. First a site must be chosen to place the reservoir, preferably at the same level as the pan so that the same amount of water will be pumped in and out of the pan. It will be necessary to dig a rectangular hole in the ground to accommodate the reservoir. The reservoir should be surrounded with gravel to allow drainage.

Mounting holes must be drilled into the side of the evaporation pan in accordance with figure A2 to mount a tube support that holds the tubing and cable that connects the cage filter and probe assembly to the control box. The probe assembly should fit snugly into the existing stilling well of the evaporation pan and should be leveled to insure the proper probe separation exists. A collar with a set screw is placed around the stilling well to secure the probe assembly.

With the probe assembly, filter assembly, and tube support installed on the insulated pan, and the reservoir in place, the tubing connecting these two units to the control box can be connected. The filter assembly should be checked to be sure a 250-micron mesh filter has been installed to protect the pump motor from particle damage.

Inside the control box there is a pump motor, solenoid valve, D.C. power supply or 12-volt battery and charger. To power the D.C. power supply or battery charger an AC outlet box is provided which is cabled to an external connector. This connector should be connected to a 105-132 VAC at 60 Hz that delivers at least 0.5 ampere. An optional connector to accommodate a DARDC cable is positioned next to the AC connector. The mating connectors to both of these connectors are called out on the wiring diagram (fig. A1).

After connecting the system and adding water to fill both the pan and reservoir, water can be pumped into or out of either container. The power switch should be in the "DRAIN" position and the switch next to the solenoid valve should be switched to "DRAIN RESERVOIR" to fill the pan or in the "DRAIN PAN" position to drain the evaporation pan. This process should be used until a water level close to the level of the probes is obtained. Turn the system off by returning both switches to their center positions. Insert the control module and LCD module if the system has the LCD option. Switch the power switch to "AUTO." Depending on the water level in the stilling well a period of time is needed for the system to reach the neutral region. If pumping does not occur in a 3 1/2-minute period, and the water in the pan is still, the system has reached this neutral region.

After obtaining a water level in the neutral region the system should be calibrated as instructed in the calibration procedure. Care should be taken before all calibration tests to ensure that no data that has been accumulated is lost. After the calibration test has been completed and water is in the neutral region, the data collection options, DARDC or LCD, should be reset.

With the LCD option a reset pushbutton for water added and removed is located on the LCD module. With the DARDC option, the reset pushbuttons are located in the DARDC translator unit. This translator unit has two counter cards that must be reset, one for water added and the other for water removed. Resetting of these cards should be necessary only during installation. If at any time after installation the two DARDC counter cards are reset, persons operating the computer that interrogates the DARDC must be notified so that data received from the DARDC is not misrepresented. During each calibration test the DARDC cable should be disconnected so that a false count is not registered and sent to the computer.

After calibration and resetting of the data collection option, DARDC or LCD, the unit is ready for automatic operation. Before sealing and leaving the system a few critical components should be checked. The small meshed filter must be inside the cage filter, the battery charger must be switched to "FLOAT" and the LCD or DARDC reset to zero.

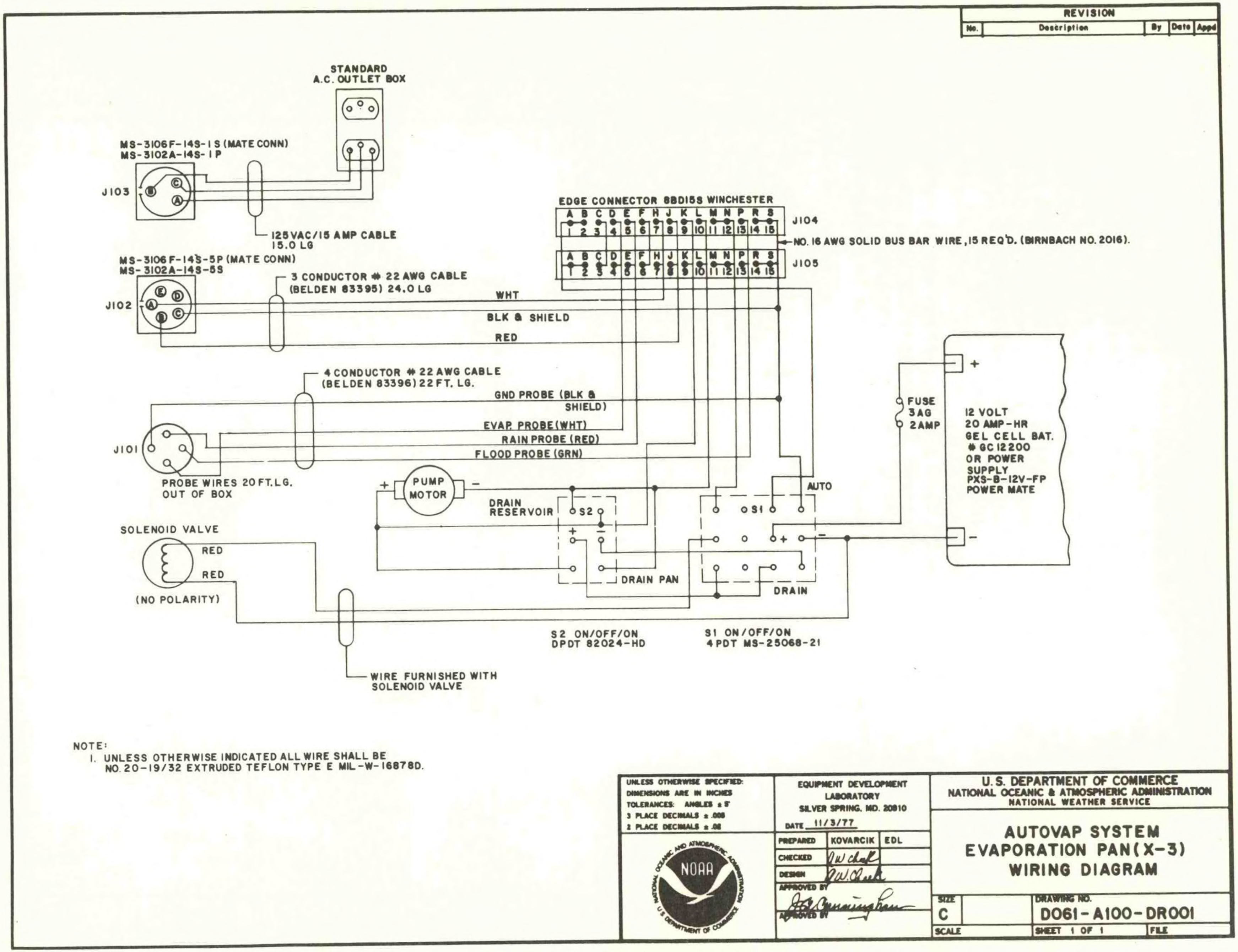

Figure A1--Wiring diagram

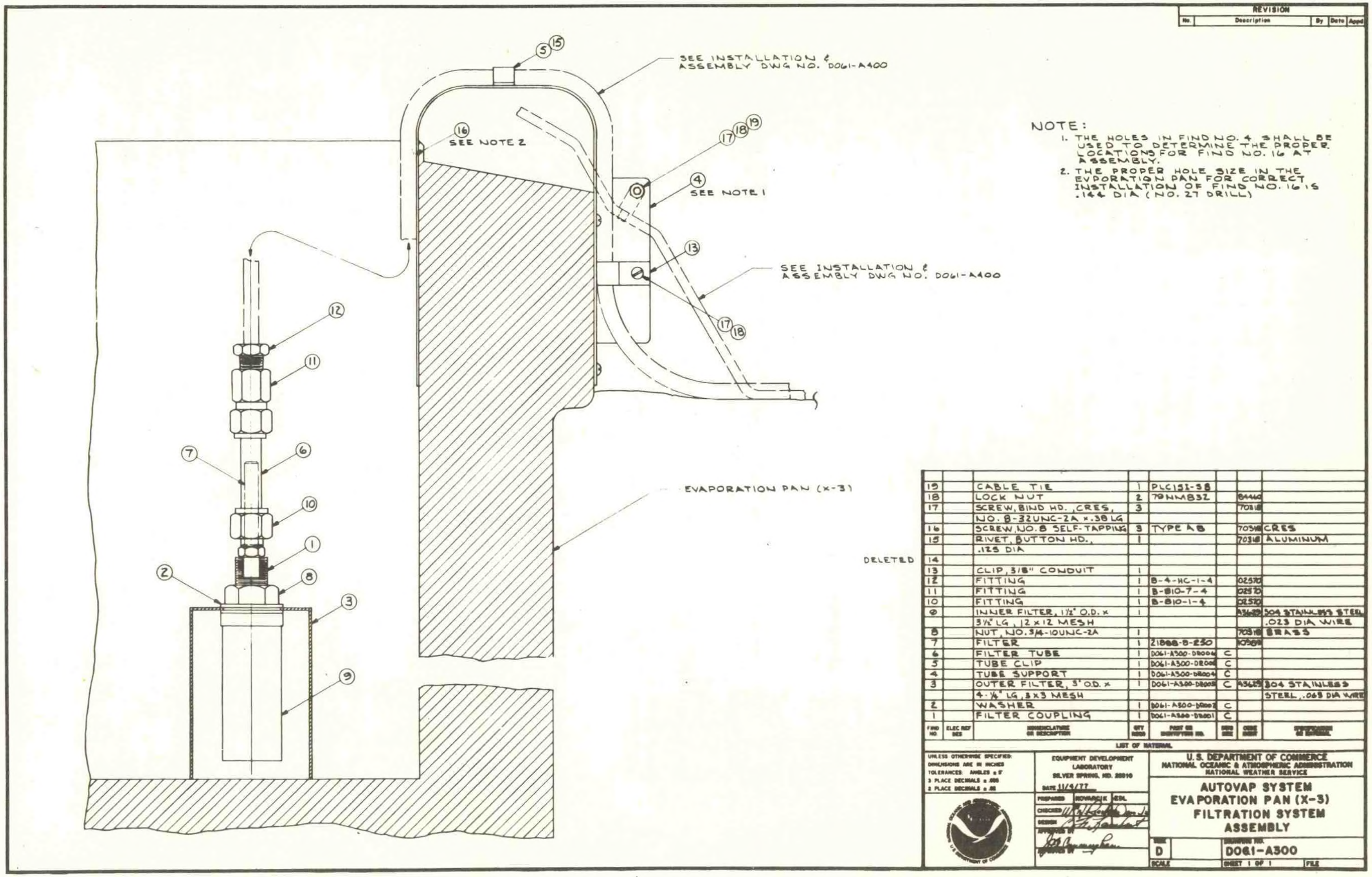

Figure A2--Filtration system assembly

APPENDIX B - CALIBRATION PROCEDURE

Periodically the calibration on the AUTOVAP system may be checked to ensure that the system is operating properly. This is accomplished by measuring the amount of water pumped into a graduated cylinder after 10 pump cycles and taking the average. The average should be 59.3 $\pm$ 2 ml. There is no specific interval between calibration checks. The system should run for several months without changing calibration. It is recommended that the calibration be checked at whatever maintenance schedule is required to keep the pan and filters free of excessive debris.

Procedure

1. After all pumping has ceased and before switching the system off, remove the DARDC cable connector from the control box if it is connected. If the system has an LCD option, record the data before starting calibration.

2. Switch the system to the "OFF" position.

3. If the system is battery operated, switch the battery charger to "Fast" charge.

4. Remove the filter assembly from the pan and place it into a container that will hold at least 600 ml (20 oz.) of water.

5. To be sure the line is completely filled with water, switch the power switch to "DRAIN" and the switch next to the solenoid valve to "DRAIN RESERVOIR." Water will pump into the container. Fill the container, then flip both switches to their center positions to stop pumping. Make sure the toggle switch on the control module is switched towards the pump motor, then flip the power switch to "AUTO." Empty the container into the reservoir and replace the filter assembly inside the container.

6. Switch the toggle switch located on the control module away from the pump motor to start discrete pumping. After 10 discrete pumps or during the tenth pump cycle switch the toggle switch toward the pump motor to stop pumping.

7. With an accurate liquid measuring device measure the amount of water pumped into the container and divide by the number of pumps (10) to get the average amount of water per pump.

8. If the system is calibrated, an average of 59.3 $\pm$ 2 ml per pump should be obtained. If not, empty the water into the reservoir, place the filter assembly inside the container, and repeat procedures 6 and 7 once more.

9. If the system is powered by a battery, switch the battery charger to "FLOAT." If the system is equipped with an LCD option reset the display with the push button switch mounted on the LCD module. Reconnect the DARDC cable if this option is installed.

10. Close and seal the control box.

If the average value obtained is incorrect, four possible causes can be checked and corrected. First, the battery voltage should be measured and the battery changed if the voltage is below 12 VDC. Another possible cause is a clogged 250-micron filter located in the fitting above the outer filter. (fig. A2). To correct this, the filter must be removed and rinsed clean, then replaced. Next, a measurement should be made of the voltage on the pump motor. This voltage should measure 8.50 $\pm$ .01 VDC on test point D on the control module when the pump motor is not pumping. To adjust this voltage a potentiometer (R30) is located next to the heat sink which is turned clockwise to increase the voltage. If all of the above corrections fail to yield a correct calibration then the pumping time circuit on the control module must be changed. To increase the pumping time a potentiometer (R14) located next to the LED is turned clockwise. Changes in the setting of the potentiometers should be made only after the battery and filters have been checked and only if the measured average value is within 15 ml of the required 59.3 ml. If not within this tolerance, the control module should be replaced and the calibration procedure repeated.

Another adjustment, that does not affect the amount of water that is pumped, is the 3-minute timing circuit which can be adjusted by a potentiometer (R6) located nearest the center of the control module. To increase the time, turn the potentiometer clockwise. The potentiometer can be adjusted from 1.5 minutes to 8 minutes.

The remaining potentiometer (R25) located nearest the pump motor will adjust the voltage at which the LED will turn on. This LED indicates a low battery voltage when it is on. At voltages below 10.5 VDC the LED will come on after a pump and remain on. Above this voltage the LED may come on during a pump but will not remain on. The LED may come on when the system is turned on but should not remain on after the first pump. Turning the potentiometer clockwise increases the voltage at which the LED turns on. Adjustment of this potentiometer should not be attempted without a variable power supply that will deliver 2 amperes at 10.5 to 12.0 VDC.

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